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# POWER SYSTEM PROTECTION ASSESSMENT OF A MINI-GRID: CASE OF NEPAL

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***ABSTRACT:*** The standalone micro-hydro projects when interconnected provides various benefits. Interconnection of MHP improves power quality, higher reliability of the distribution system. Interconnection of MHPs causes the system to lose its radial power flow, besides the increased fault level of the system. The effect of MHP on power flow as well as short circuit level of the network is investigated through simulating the isolated mini-grid network feeder using ETAP. The result is analyzed for the different cases and it is found that the performance of the mini-grid system considering line losses and voltages was within acceptable limits for the transmission network.

***KeyWords:*** mini-grid, ETAP, contactor, relays, micro-hydro, power quality, reliability, Interconnection

# I. Introduction

Rural electrification in developing countries like Nepal are not only to electrify the household but also intended to serve the economic and social targets. Therefore, electrification helps in rural development through reducing drudgery, creating economic opportunities and improving the quality of life of the rural people and expected to increase the per capita GDP, as most of the poor of the poorest live in the rural areas.

In context of Nepal about 83 % of total population lives in rural area. Even though the electrification in rural areas is difficult, it opens the door of many possibilities for the development of the rural areas. Therefore, the government of Nepal gives priority for rural electrification and is mainly done in two ways: with the extension of national grid and with the isolated plants mostly micro hydro plants, solar home system etc.

As country is mountainous with mostly scatter settlement, grid connection and extension is most of the time unfeasible due to the high installation cost. This increase in cost is mainly due to transmission and distribution losses, less number of consumer and low rate of consumption of electricity. Apart from this, due to the topography installation works are hard and results in huge capital investment. Due to these drawbacks the quality of electricity in rural area is not up to the national standard.

The second option is off grid connection i.e. decentralized isolated plant which are mostly micro hydro constructed for the rural electrification. In order to promote standalone micro hydro and solar home systems, the government of Nepal along with donor agent (UNDP, WB, Danida, and GTZ) are providing subsidy to promote community-based energy schemes.

### *A. Micro hydro develop in Nepal*

Harnessing of energy from the water is not new for Nepal .The first electricity hydropower plant, from the water was established on 1911 AD in the name of Pharping Power Plant at Pharping, Kathmandu. Even though the first hydropower plant was established a century ago, development is still at a slow pace and the electrification programme has challenging issues for both rural and urban areas of Nepal.

Water is plentiful in the rugged hills of Nepal. Micro-hydro in this areas is more practical and cost effective alternative to the national grid for rural electrification. This form of renewable energy has been increasingly used for the decentralized rural electrification for the last two decades. “External technical assistance, innovation and government policies have added the fuel for the widespread establishment of micro hydro technology”.

### *B. Satus of Micro hydro in Nepal*

Hydro power between greater than 5kW to 100 kW is categorized as micro hydro and has the potential to be a major source of energy for rural areas [1] (AEPC guideline 2008, p32). With supporting policies and initiation by the government of Nepal, large numbers of Micro hydro power plants have already been constructed. As a result, many rural communities are able to light their houses through these projects otherwise they would have had to live in darkness for a more few decades.

In comparison to the other form of renewable energy, micro hydro plant can be manufactured locally and it is cheap to install and run the plant. This decreases overall cost of the micro hydro plant and make it technical and economically feasible for the rural electrification. Over the past four decades, 2,500 micro-hydro plants have been constructed in Nepal generating a total of 21.27 MW.

# II. Litrature Riview

In [2], they described the supply of power to remote rural areas from Small Hydropower Projects (SHP)/renewable energy power projects in cost effective and sustainable manner requires the optimum design of mini-grids. It deals with the design of mini grids of nine SHP plants running in isolated mode only for 8 hrs/day wasting the energy of 16 hrs/day. Based on system layouts, transmission routing, line length and selection of conduc¬tor, different alternates of mini-grids were developed to connect these SHPs together as well as with the near-by 33 kV grid substations located at approximately 15, 17 and 9 km from nearby SHPs in order to improve the load factor. The optimization of these alternates on the basis of the Break-Even-Point (BEP) has indicated that one of the alternates has been found as optimum alternative for the study area with shortest line length, low line losses and minimum capital investment for the mini-grid implementation.

In [3], they have studied the design of low-cost automatic synchronizer consisting of few digital gates, relay and contactor as main component, which is useful to form mini-grid with power plant using Induction Motors as Generators (IMAGs).

In [4], there are reviewed the development of Mini-grid laboratory in Kathmandu University, Nepal. The paper focuses on the step by step procedure for developing the laboratory and challenges faced during the building process. It also highlights the importance and scope of this laboratory in context of the development of mini-grid power systems in Nepal.

In the paper [5], they reviewed the performance study of the laboratory fabricated test kit developed as a part of R&D at Kathmandu University, Nepal. The test kit contains lab-fabricated Induction Generator controller (IGC) unit and an Automatic Synchronizer (AS). These two units can be individually switched on or off (as per the necessity) by a simple switch. The test kit is connected in various test environments to simulate both isolated and grid connected scenario. The performance of the kit is evaluated on the basis of its synchronizing ability and power sharing ability keeping in mind other factors voltage regulation and protection issues.

*A. Time current characteristics of MCCB*

Circuit breaker time-current characteristic curves are principally [6] a function of the type of trip unit and its settings. A typical time-current characteristic curve is shown in Figure below for a 100 A frame size molded-case circuit breaker in open air at rated temperature, usually 40°C. At the current level setting of the instantaneous element, that is, with no intentional time delay, the operating time drops abruptly to the time required by the circuit breaker mechanism to open the contacts plus arcing time. The fault is cleared at the horizontal line labeled “maximum instantaneous opening time.”



Figure 1: Typical TCC Curve for a 3-Pole 100 A model DH100

*B. Low Voltage Contactor*

In papar [7], Contactor is a device that uses a small control current to energize or de-energize a load. Contactors can handle high amounts of current and are also combined with overload relays to create motor starters.

A contactor works on the principle of Electro-magnetism. It comes under the category of switch gears and all the switchgears performs the same function of Switching.

A contactor consists of mainly 2 parts-fixed and movable jaws. The fixed jaws are firmly connected with the circuit and is a provided with a COIL having movable jaw as soon as current is allowed to flow from the circuit the

COIL gets charged and due to electromagnetic effect, it attracts the movable metal jaw, thus the circuit is complete with the CONTACT provided by the movable jaw. This is the functioning of contactor. When current through the circuit ceases, coil demagnetizes and movable jaw is pulled apart.

The contactor used [8] is “Siemens Power Contactor TF model”. 3TF power contactors are suitable for switching and controlling squirrel cage and slip-ring motors as well as other AC loads, such as solenoids, capacitors, lighting loads, heating loads and transformer loads.

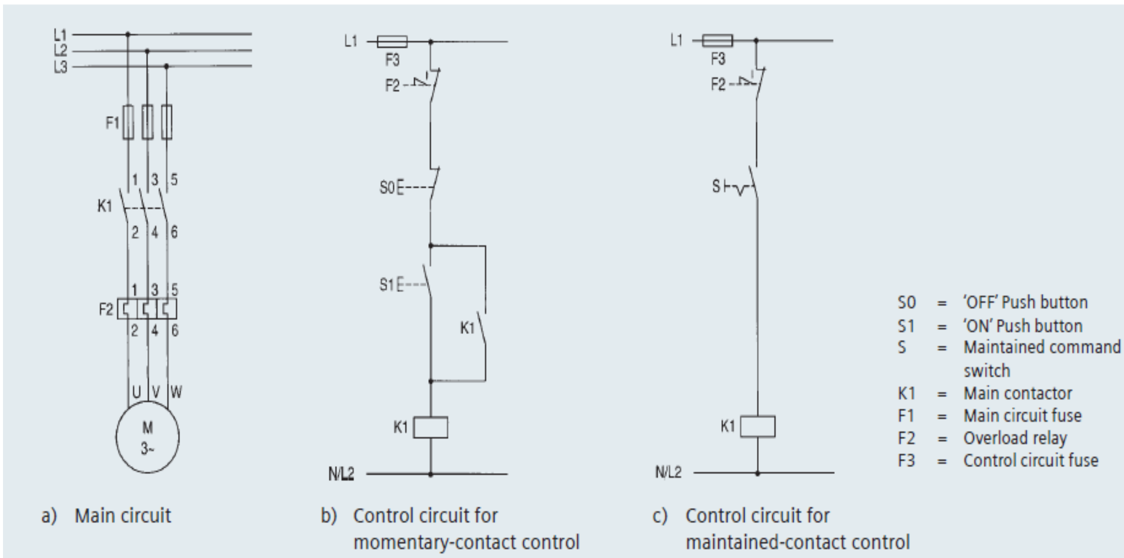


Figure 2: Typical Circuit Diagrams of 3TF Model Contactor

*C. Standard for Small Hydro Development*

This guideline [9] is to provide guidance for selecting voltage level for power evacuation, bus bar arrangement for connected switchyard, interconnection with isolated load or grid, selection of necessary protection scheme for the selected grid interconnection developed by Alternate Hydro Energy Centre (AHEC), Indian Institute of Technology

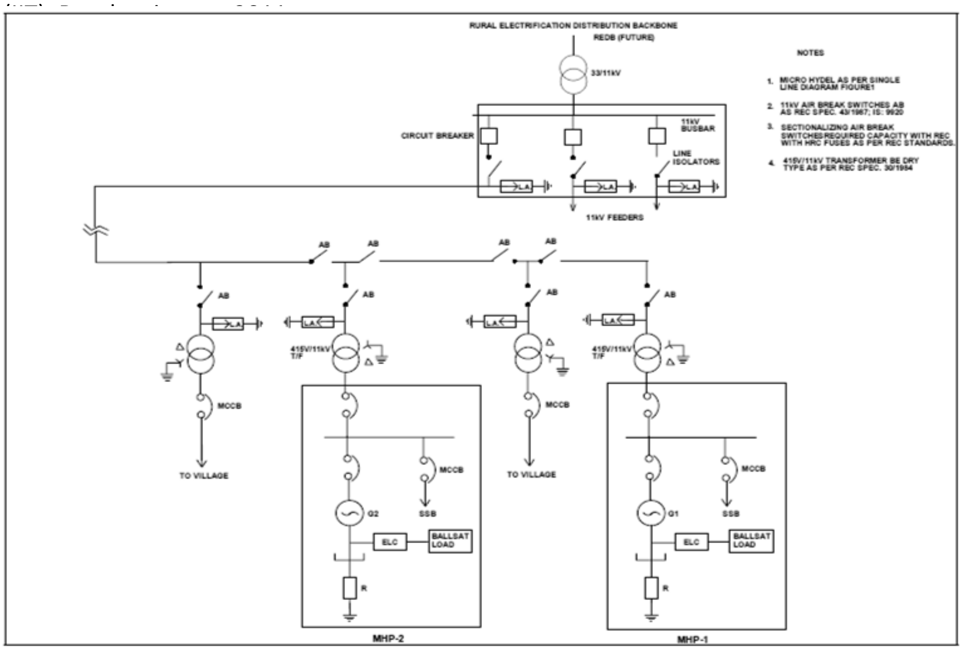


Figure 3: Micro-hydels mini-grid single line diagram

## III. Methodology

The research is carried out as the technical study of the mini-grid in the Baglung district of Nepal. The study is focused on technological aspect of the mini-grid system and mainly focus on protection system and their protective device.

The type of the technology used for all the existing micro hydro power plants is assessed and for the inter-connected MHP in mini-grid network and this work analysis has been done in the following steps and shown in figure 4.

### A. Desk Works:

In the beginning, literature review has been done by collecting the background information of the research to understand the main gist of the study. Secondary data is collected from the past studies, various reports, internet sources, various journals and books to gain understanding of the core of the research in the mini-grid.

### B. Formulation of Questionnaires

After reviewing the related papers, relevant questions related to the MHP were prepared with detailed requirements specially focusing on protection system adopted for the system. The questions were designed mainly for the Mini-grid Engineer. The questionnaire is carried out into following different sections:

*Technical information*: General technical features such as electromechanical components and other related components of the six existing MHPs.

*Protection System:* Mainly focus on the protection system that are incorporated for the safety due to different fault in the system.

*Protection Devices:* The different type of protective device and switchgears used for the disconnection if any abnormality occurred in the system.

### C. Data Collection

*Primary Data:*

Primary data is collected in two levels. One in the field level where all the technical data are taken with the help of technical operator of each of the plant who is directly involved in the technical operation of the control and protection of the individual MHP and mini-grid system. Self-visual information from field and interview method is mainly used for this purpose. Another is the central data collection. In central level data collection, information about existing policies and future plans of government with regards to development of mini-grids is taken. For this, interview methods are used with officials of RERL/AEPC who are responsible for execution of different renewable energy projects in the country.

*Secondary Data:*

The major secondary data for this study is the data of different micro – hydro and other sources of renewable energy in this research area which is collected from RERL/AEPC. Similarly, data from secondary sources like central bureau of statistics, taking reference from similar studies done in other countries, internet sources, and literatures are also used to extract necessary information.

### D. Data Analysis

*Load Flow:*

After collecting the technical data from the field, a load flow analysis is done using ETAP software whose result output provides different parameters. The load flows are conducted for the different cases of the mini-grid to help in studying the behavior of the system.

*Fault Analysis:*

From the technical information of the mini-grid, the protection system is modeled into ETAP [10] and different types of faults are introduced in different buses to extract the results and compare with the given system.

*Assessment of Switchgear devices:*

In this section, the devices technical data is collected e.g. rating of the devices and this is compared with the calculated values.

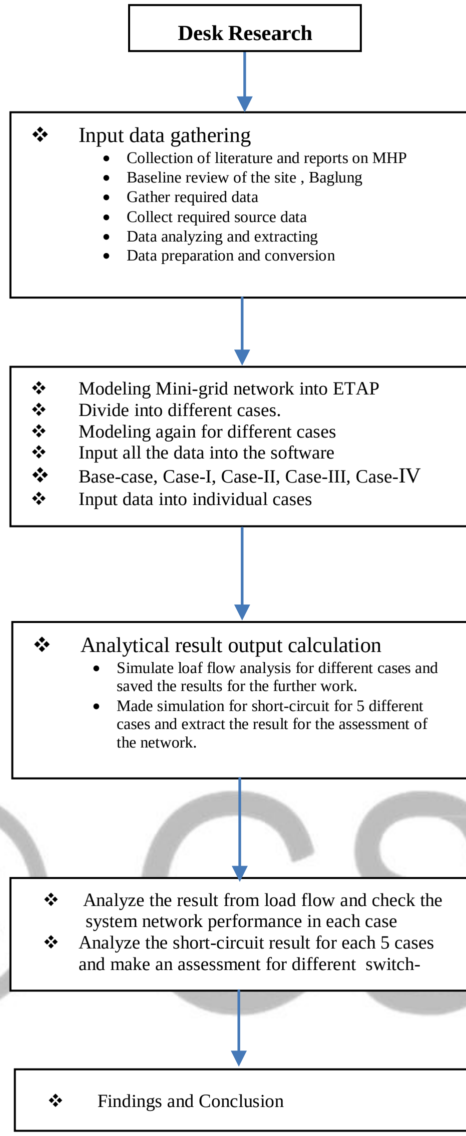


Figure 4: Block Diagram of Summary of Activities to be Carried Out



## IV. System Overview of Mini-Grid, Baglung, Nepal

Nepal's first mini-grid project called "Urja Upatyaka Mini-grid Project" was initiated by synchronizing six micro hydro plants of Baglung district of Nepal. It is in regular operation since July 2011. Honorable Minister for the Ministry of Environment Hem Raj Tater inaugurated the mini-grid on 20 March 2012.

Micro-hydro projects constructed under Rural Energy Development Programme (REDP)/ Renewable Energy for Rural Livelihood (RERL) program of Alternative Energy Promotion Centre (AEPC), from Kalung river of Rangkhani, Sarkuwa, Damek and Paiyunthanthap Village Development Committee (VDCs) from southern part of the district are connected in the mini grid. Total installed capacity 107 kW electricity produced from isolated mini-grid is connected via 7.7 km long 11 kV transmission line. One thousand and one hundred and seventy-eight households are benefited from this mini-grid system.

This mini-grid was established with the financial and technical support of "Renewable Energy for Rural Livelihood (RERL)" program of AEPC. Urja Upatyaka Mini-grid Cooperative has been established for the regular operation of the mini-grid. According to the management process the mini-grid cooperative will work as a grid operator and electricity distributor whereas every isolated micro hydro project will work as an individual electricity producer.

*A.* *Layout of the mini-grid*

Six micro hydro plants which are producing electricity from the same river in various areas are supposed to be interconnected to form the MV mini-grid in Baglung district as the pilot Project by UNDP/REDP. The transmission line passes from each of the power houses along the river side starting from the Upper Kalung Khola to Theule Khola MHP. Since the power is to be transmitted at the high voltage than the previous micro hydro, adequate safety should be considered. Interconnected with each other has to be done, synchronization is essential and no doubt that frequency and voltage should be within the range for the synchronization.

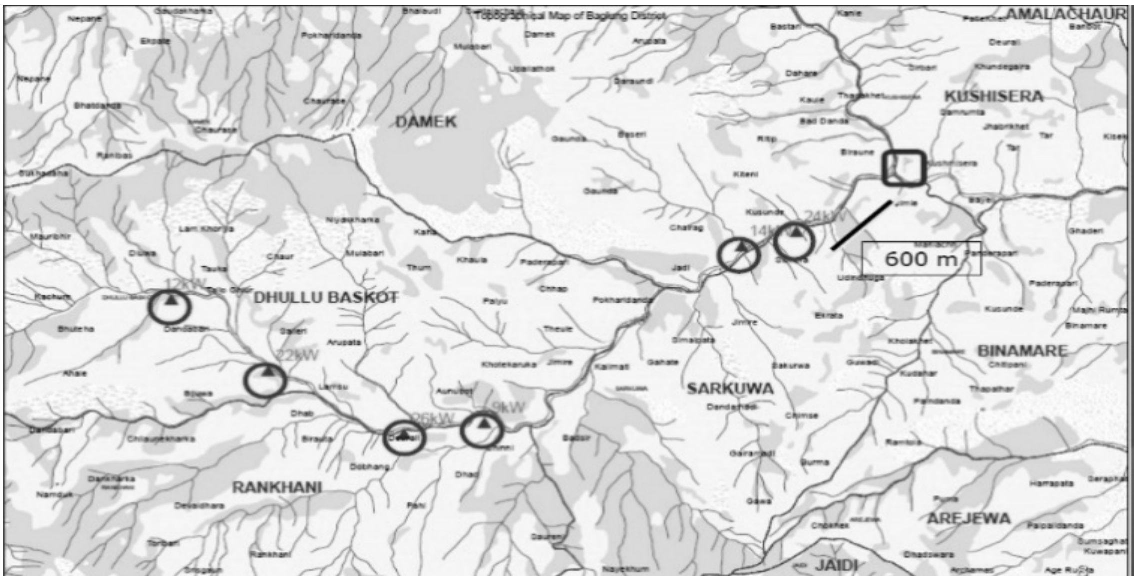


Figure 5: Six plants shown in topological map



*B.* *Single line Diagram of Mini-grid*

All the power plants is connected in the 11kV mini-grid networks with the step up 400V/11kV transformer. Whereas other line is the existing distribution line of 400V which directly goes to the present load centers covered by the respective MHPs. For the large power plant Theule Khola, Urja Khola I and Kalung MHP 50 kVA transformer is used where as in the remaining three power plants with the low capacity 30 kVA transformer is to be installed.

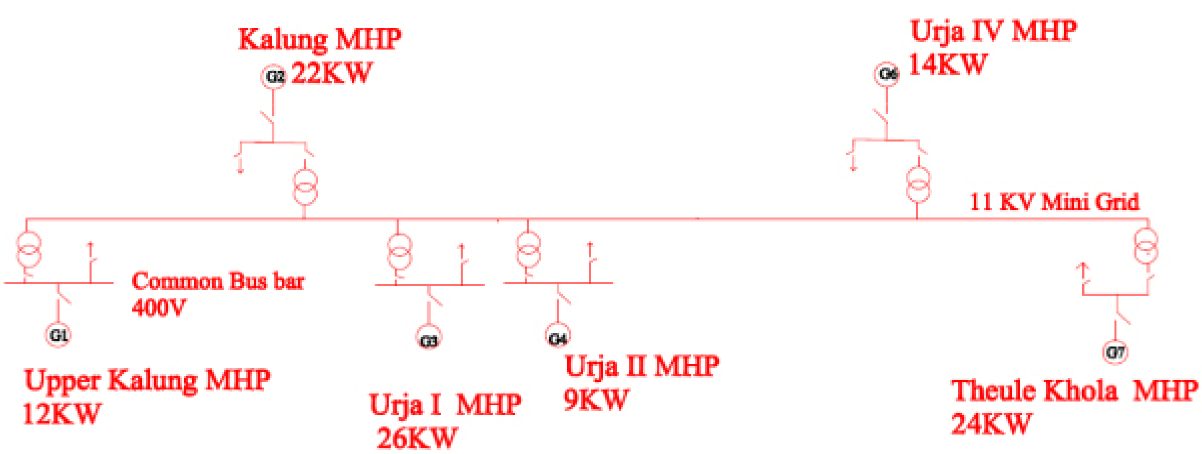


Figure 6: Single line diagram of Mini-grid

## V. Reasult And Analysis

All the six MHP are modeled into ETAP software and first input all the parameters of the different component and it has been simulated in the program and in this case load flow is done in standalone mode of the plan for the existing performance before interconnecting these all six plants.

### *A. Standalone Mode of Operation*

*1.) Urja I MHP (26kW):* The model in ETAP of Urja-I MHP (26kW) is presented below in the program and all the data are input to the respective field and the made the analysis.

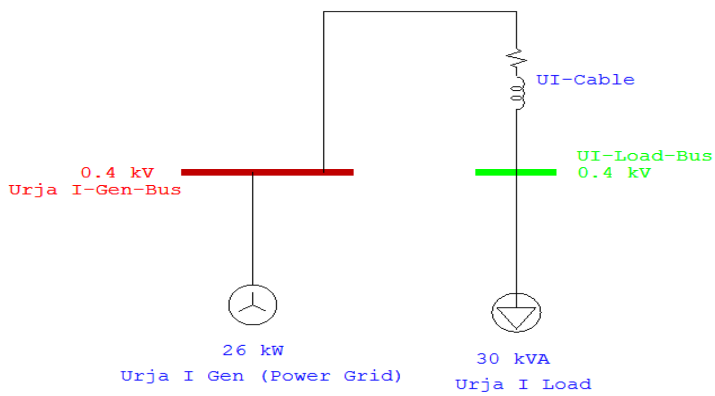


Figure 7: Diagram for the simulation for Urja-I MHP

When there is balance loaf flow analysis is made in the ETAP program, there is the result that found in the standalone case is shown below:

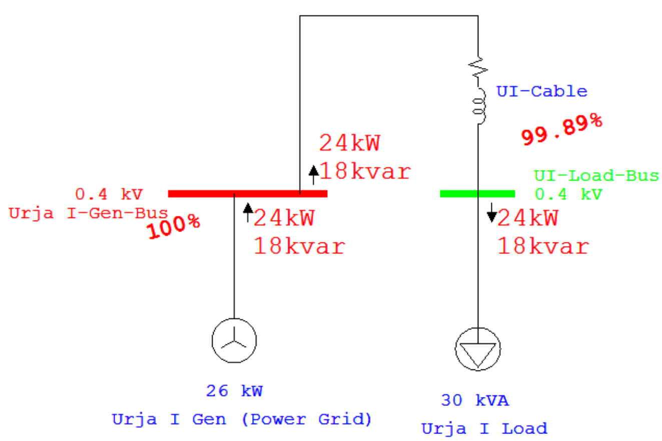


Figure 8: Result of load flow shown in the circuit model

From the above result from load flow it is found that the loss in to the system is negligible and found that the voltages in generator bus is 100% and, in the load, bus is 99.89%. This indicates that there are no negligible losses to reach to the required point.

*2.) Urja II MHP (9kW):* The model in ETAP of Urja-II MHP is presented in the program and all the data are input to the respective field and the made the analysis.
Now after doing the load flow analysis, the following result is found and it is displayed into the ETAP diagram. The load flow is made after input of all the information about the generator, load and line parameter of the plant. From the result, it is found that there is negligible voltage lag in the load bus and it is within the permissible limit to the system consideration.

*3.) Kalung Khola MHP (22kW):* The model in ETAP of Kalung Khola MHP is made and all the data are input to the respective field and the made the analysis. The load flow of this standalone system is presented in annex and there is some explanation also. It is seen from the result that there is only 0.1% lower voltage with respect to the reference voltage which is very small and it is within the limit of the system.

*4.) Upper Kalung MHP (12 kW):* The model in ETAP of Upper Kalung Khola MHP (12kW) is presented below in the program and all the data are input to the respective field and the made the analysis. When load flow is run for this above system, the following result would find from the simulation. The result shows that there is not distorted voltage magnitude in the load bus and it is found 99.94% and which is satisfactory for the given system.

*5.) Urja IV MHP (14kW):* The circuit diagram of the system of this plant having capacity is model in ETAP having synchronous generator, lump load and line also for the connection of load and generation of the system. The load flow when run into the program then the result of the above MHP found as follows. The result indicates that the system is good with the prospect of voltage for the load bus 99.94%. It is shown that the system is running in the full load condition and there is no any reserve power to the plant because the plant is 100% loading condition.

*6.) Theule Khola MHP (24kW):* The plant having capacity 24kW is plotted into ETAP and after input all the information of generator and the load and line and found the result. When this diagram is simulated into EATP and run load flow, the following result is found and it is found the further discussion. Here the result indicates that the voltage magnitude at generator bus is 100% and in load bus is 99.89% and is operating in full load which is generation 100% of its capacity and the load is also equal to the generation.

*B. Mini-grid Mode of Operation*

*1.) 15% Load into the System:* This case having load is only 15% of full load capacity of the mini-grid that means only 16kW of load. So some plants are shut down and remaining plants are in operation to fulfill the demand load. Only two generators Urja-I MHP (26kW) and Upper Kalung MHP (12kW) are in operation and remaining are in off mode. The circuit diagram in this case is shown below.

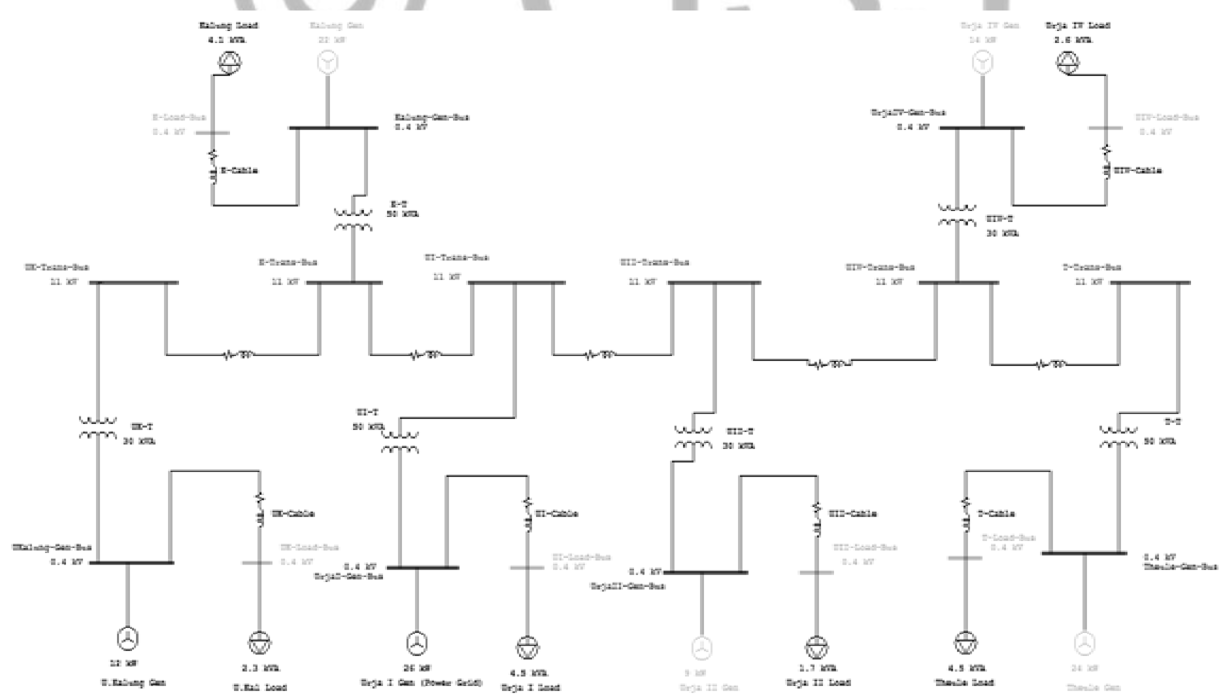

Figure 9: Mini-grid diagram having two generators in operation

From the load flow, one of the parameters to check the voltage profile of each of the buses if the mini-grid id operating in such mode is found that

TABLE 1: VOLTAGE PROFILE IN EACH BUS

| SN | Bus ID | Nominal kV | Voltage (kV) | % drop of Voltage |
|---|---|---|---|---|
| 1 | Kalung-Gen-Bus | 0.4 | 0.398 | 0.500 |
| 2 | K-Load-Bus | 0.4 | 0.398 | 0.500 |
| 3 | Theule-Gen-Bus | 0.4 | 0.398 | 0.500 |
| 4 | T-Load-Bus | 0.4 | 0.398 | 0.500 |
| 5 | UII-Load-Bus | 0.4 | 0.398 | 0.500 |
| 6 | UI-Load-Bus | 0.4 | 0.400 | 0.000 |
| 7 | UIV-Load-Bus | 0.4 | 0.398 | 0.500 |
| 8 | UKalung-Gen-Bus | 0.4 | 0.400 | 0.000 |
| 9 | UK-Load-Bus | 0.4 | 0.400 | 0.000 |
| 10 | UrjaI-Gen-Bus | 0.4 | 0.400 | 0.000 |
| 11 | UrjaII-Gen-Bus | 0.4 | 0.398 | 0.500 |
| 12 | UrjaIV-Gen-Bus | 0.4 | 0.398 | 0.500 |
| 13 | K-Trans-Bus | 11 | 10.973 | 0.245 |
| 14 | T-Trans-Bus | 11 | 10.970 | 0.273 |
| 15 | UII-Trans-Bus | 11 | 10.972 | 0.255 |
| 16 | UI-Trans-Bus | 11 | 10.972 | 0.255 |
| 17 | UIV-Trans-Bus | 11 | 10.970 | 0.273 |
| 18 | UK-Trans-Bus | 11 | 10.975 | 0.227 |

Voltage at each bus is very good during the operation of the grid. From the table it is seen that there is only max of 0.5% of voltage is changes with the nominal voltage. So, the system is very good voltage profile.

TABLE 2: TRANSMISSION LINE PERFORMANCE

| SN | From Bus | To Bus | Power Flow (kW) | Power Losses (kW) | % Voltage Drop |
|---|---|---|---|---|---|
| 1 | K-Trans-Bus | UI-Trans-Bus | 6.845 | 0.001 | 0.010 |
| 2 | UII-Trans-Bus | UIV-Trans-Bus | 5.651 | 0.001 | 0.010 |
| 3 | UI-Trans-Bus | UII-Trans-Bus | 7.006 | 0.000 | 0.000 |
| 4 | UIV-Trans-Bus | T-Trans-Bus | 3.581 | 0.000 | 0.010 |
| 5 | UK-Trans-Bus | K-Trans-Bus | 10.112 | 0.002 | 0.020 |

There are 5 transmission line to connect these six plants and maximum power carried is 10.112kW by the transmission line which is between Upper Kalung MHP and Kalung MHP and active power loss on that transmission line is 0.002kW and voltage drop is only 0.02%.

*2.) 35% Load into the System*: In this case, 3 plants are on operation to fulfill the demand of the system. The operating plants are Urja-I MHP (26kW), Upper Kalung Khola MHP (12kW) and Urja-IV MHP (14kW). The result found that the lowest voltage is 0.396kV in three buses. These buses are Kalung load bus, Theule Gen bus and Theule load bus. The maximum voltage drop is only 1% for this case. And when talking about the line performance, maximum power flow in the transmission line is 8.230kW and the transmission line is in between Urja-IV and Theule MHP. But the line loss in only 0.002kW and maximum voltage drop in only 0.02%.

*3.) 58% load into the system:* The lowest voltage is 0.395kV at Urja-IV load bus and have the voltage drop of 1.25% in this situation. The power flow in the transmission line on the portion of Urja-IV and Theule Khola MHP and the amount of power is 10.052kW but the active power loss is only 0.002kW and voltage drop is 0.02% for the system for this case.

*4.) 100% load into the system:* there is no any voltage losses into the buses because every generator have its own local load and there is no any power exchange into the grid.

*C. Protection System*

The mini-grid understudy assesses the protective relays for the protection of the system as per IEEE1547 and IEEE Std 242. The system is considered all the protective relays:

- Over current relay
- Voltage restraint over current relay

- Earth fault relay
- Under/over voltage relay
- Under/over frequency relay
- Phase sequence relay
- Check synchronizing relay
- Reverse power relay
- MCCB (Moulded case circuit breakers)
- Power contactors

From the assessment, it is found that the relays are sufficient for the protection.

The assessment of switchgears is made by the introduction of shirt circuit analysis using ETAP simulation software. From the software we introduced the 3-phase fault in the different bus bars and calculated the maximum fault current.

The maximum fault current found to be 1.3484kA when there is a fault in the Urja-I Load bus. But the fault current carrying capacity of the contactor for type-2 is only 250A. So, it shows to burn the contactors.

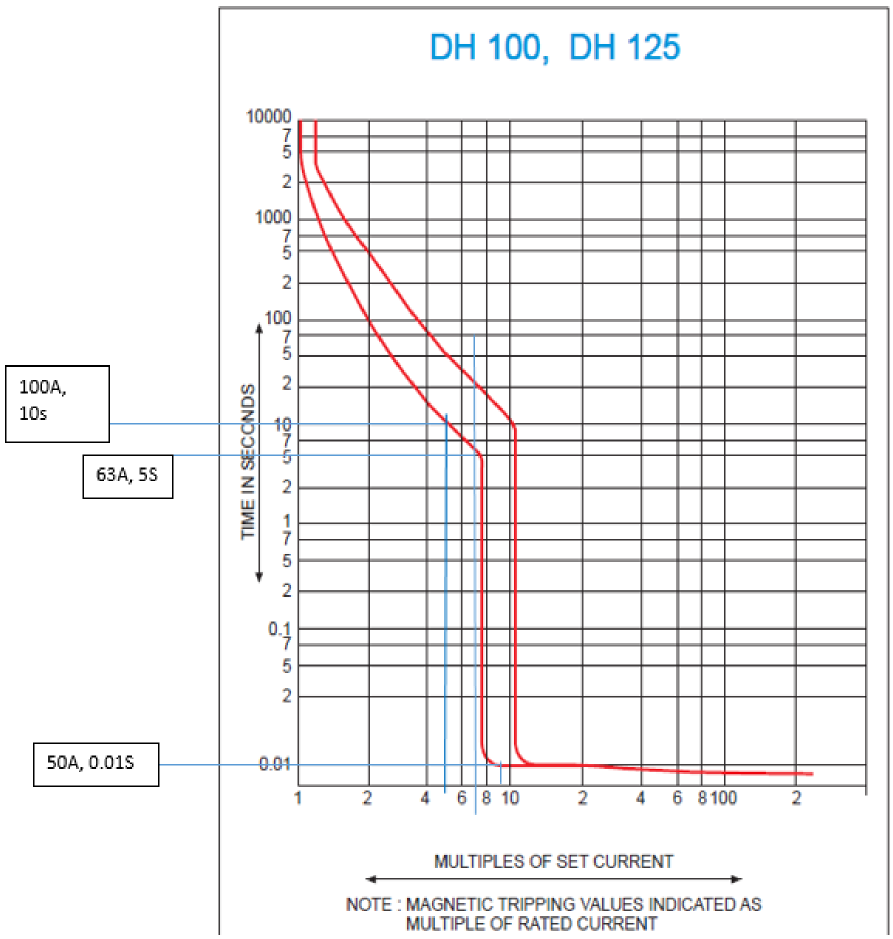


Figure 9: TCC Characteristics of MCCB of 100A

When making the assessment of the MCCB used in the system for fault at load but of Urja-I and found from the TCC characteristics is 10sec which is very large time for the tripping of the MCCB. So, the sizing is not proper.

Similarly, we can calculate the remaining buses and found that all the selected switchgears are not the proper size from the protection point of view.

## VI. Conclusion

Interconnection of MHP to form mini-grid provides an improved power quality, higher reliability of the distribution system but the result found that the system is sufficient for power transfer and regulation of the transmission line consideration that only 0.02kW losses. The voltage limit is found to be 0.395kV-0.4kV and 10.95-11.00kV in the buses when the load is varying from minimum to maximum.

For power system protection, most of the protective relays are considered but Loss of mains is not considered and this impacts the system if the grid suddenly turns OFF or ON and this has an impact on the generation system as well.

The size of MCCB is not appropriate and it is found that it will not trip as main protective device when a 3-phase fault occurs into the system it will give hazards to the system if the other backup protection device does not work properly. Here contactor is the backup protection device to clear the fault to safeguard the system.

The contactor that is used in mini-grid is not the proper size and appropriate for protection from the fault current and it is found that it will not be able to withstand the fault current. This is not the proper device for the protection for the generator or mini-grid system.

## VII. Acknowledge

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## References

[1] U. C. S. P. Ltd, "Renewable Energy Year book of Nepal 2011", AEPC, 2011.

[2] M. S. &. A. S. S.N. Singh, "Design of Mini-grid for SHP Plants," HYDRO NEPAL, no. Issue 7, July, 2010.

[3] V. B. R. D. B. Adhikary, "Design of an Automatic Synchronizer for Connecting Induction Motors as Generators in Mini-Grid Systems," KU Publication.

[4] R. D. B. A. R. M. &. N. V. Bhandari, "Establishment of Mini-Grid Laboratory in Kathmandu University".

[5] V. B. B. A. R. M. a. N. S. R. Dahal, "Performance evaluation of laboratory test-kit in Mini-Grid system".

[6] Catalog of L & T MCCB India for 100A capacity.

[7] S. S. Rao, "Switchgear Protection and Power Systems", Khanna Publishers; Daryaganj, Delhi-110002, 2010.

[8] Catalog of Siemens Contactor of 3TF class India limited.

[9] IIT-Roorkee, "Standard/Manual/Guideline for small hydrodevelopment Power Evacuation and Interconnection", May 2011.

[10] ETAP Manual for the simulation and data entry of the program.